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TEST RESULTS OF EARTH PENETRATORS.

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Donald Randall

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Three test series were conducted to observe the stability of small length-to-diameter ratio projectiles penetrating natural earth and concrete clad earth targets. Impact velocities were from 1300 ft/sec to 2000 ft/sec. A wide variety of projectile shapes were found to penetrate stability at a variety of angles-of-attack (yaw) and at impact obliquities of zero and twenty degrees. A self-obturating sabot was developed which launched → next page

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20. ABSTRACT (Continued)

projectiles at reproducible velocities but with an unpredictable angular velocity.

CONTENTS

ILLUSTRATIONS

SECTION 1

INTRODUCTION

The stability of projectiles traveling through an earth medium has been a matter of continuing interest. Several investigators have conducted experimental and computational programs to measure or predict the course of projectiles in typical earths. The value of penetration calculations has been limited by an incomplete understanding of the physics of penetration and by the cost of performing computations of problems employing complex models with fine space and time resolution. Experiments had been limited by cost since work had generally been done in relatively large scales using bulky apparatus. Even though scaling relationships are incompletely understood it seemed appropriate to conduct a series of tests in natural earth media utilizing small scale models and a simple launcher. Such a series of tests could be valuable in screening potential shapes and in observing penetration properties at impact velocities higher than those feasible in larger scale with existing launchers. With these aims in mind, Physics International Company (PI) contracted to conduct a series of tests to observe the penetration stability of a group of small length to diameter ratio (L/D) shapes launched from a modified 57 mm cannon.

The tests were conducted in three series. Some of the diagnostic and launching techniques were modified between series in response to the results of the previous series.

SECTION 2

EXPERIMENTAL PROGRAM

2.1 LAUNCH SYSTEM

The launch system utilized in all three of the series conducted under this program is shown in Figure 1. The barrel of a standard 57 mm rifle was reamed smooth to 2.375 inch diameter and a 4 foot long extension with radial relief holes was added to relieve the gas pressure on the base of the launch package before it exited the muzzle. The launch tube was mounted on a welded steel framework which also carried a sabot stripper, a blast shield, skids for transport, and jacks for leveling.

2.2 TEST SERIES 1

Five projectile designs were used in this series. Sketches of the projectile shapes used in this and in later series are shown in Figure 2. It was the objective of the series to test these shapes at 2000 ft/sec muzzle velocity and at angles-of-attack (yaw) of 0 and 3 degrees. Impacts were to be at normal obliquity. The model projectiles were enclosed in plastic sabots which were cast in an aluminum mold shown in Figure 3 using dummy projectiles as shown. All of the projectiles had their centers of gravity 45 percent of the length (2.25 in.) aft of the tip. The remainder of the launch package consisted of a ½-inch-thick steel disk in contact with the base of the projectile and a 2-inch-thick polyethylene obturator which served as a gas seal.

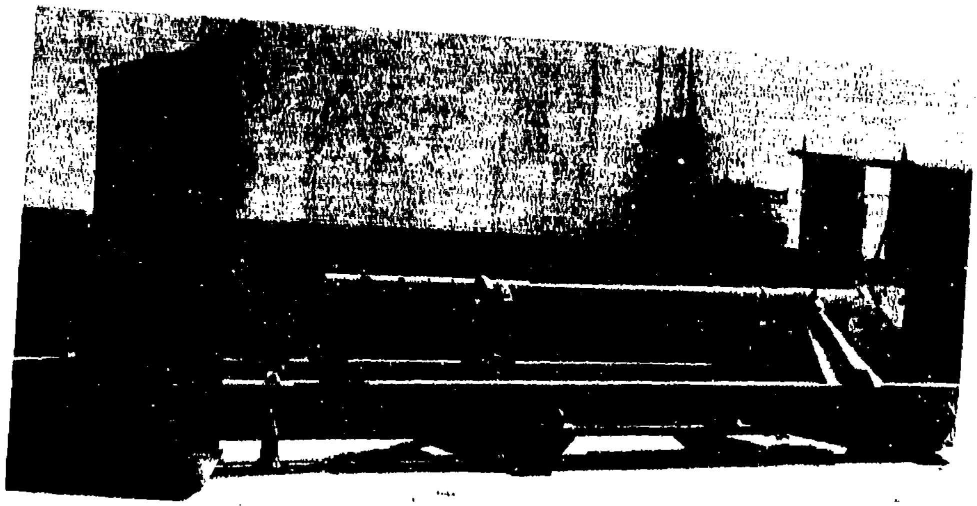


Figure 1   Projectile launcher.

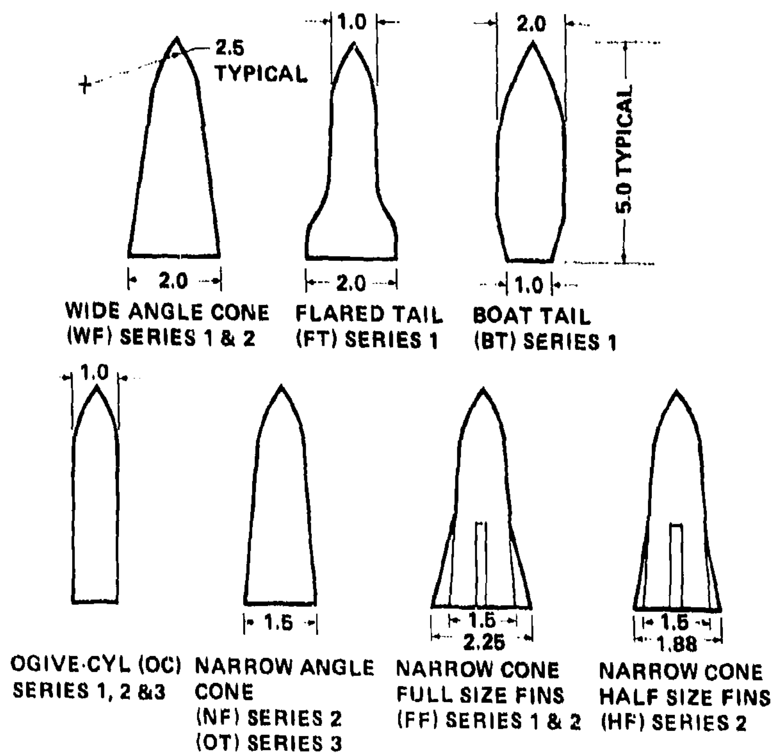


Figure 2 Projectile outlines and designations.

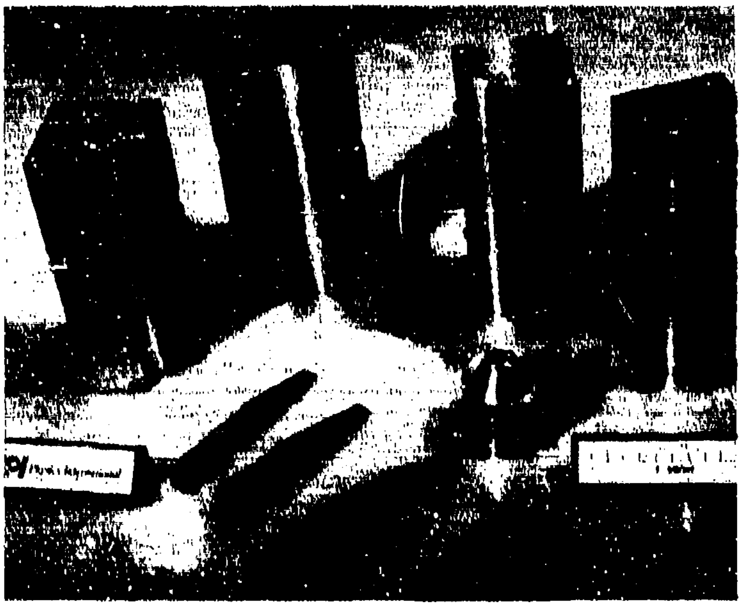


Figure 3   Sabot mold with dummy projectile.

The results of this series of experiments were diagnosed by measuring the elapsed time between a break wire on the muzzle of the gun and each of two aluminum foil switches, one on each side of a sabot stripper. Two photographic stations were established to observe the projectile in flight. The stations consisted of plywood boxes painted flat black inside with two cameras at each station observing projectile flight from two viewpoints. The illumination for exposure was by electronic flash units. The flashers were triggered by fixed time delays after actuation of one of the foil switches. The first of the stations was located immediately next to the earth bank which the models would enter. The second was located in a trench separated from the first station by a bank of earth about 54 to 60 inch thick. Figure 4 illustrates the experimental setup. An example of the photographic record is shown in Figure 5.

In the course of this first series several difficulties were noted. In order to locate the center-of-gravity of the projectiles at the desired point, it was necessary to use tungsten noses and aluminum afterbodies. The noses were secured by means of a transverse pin. In several cases the pin sheared during the penetration process and the nose separated compromising the validity of the experiment. The pusher plate and the plastic obturator followed the projectile into the hole and obscurred the details of penetration in the first few body lengths. Since a new interest had developed by this time in the dynamics of penetration in this shallow region, this loss of data became undesirable. Further, the photo instruments had proved to be of insufficient resolution to answer all of the important questions of projectile flight.

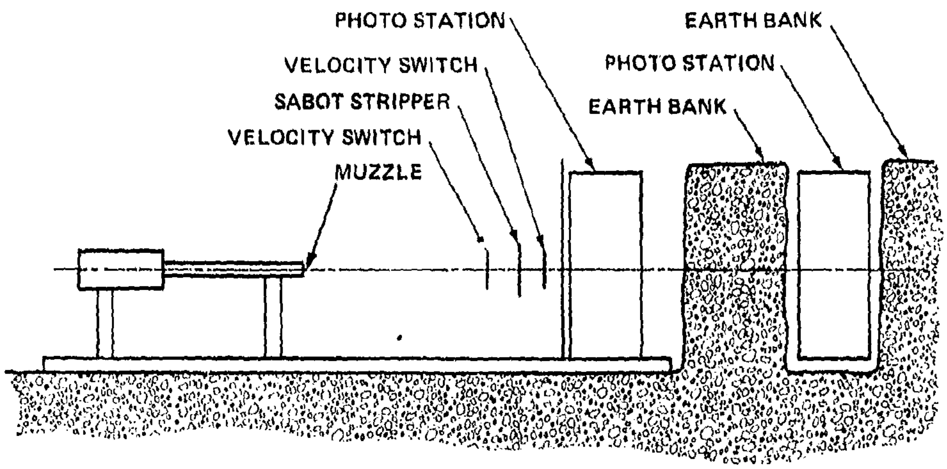


Figure 4 Experimental setup Series 1.

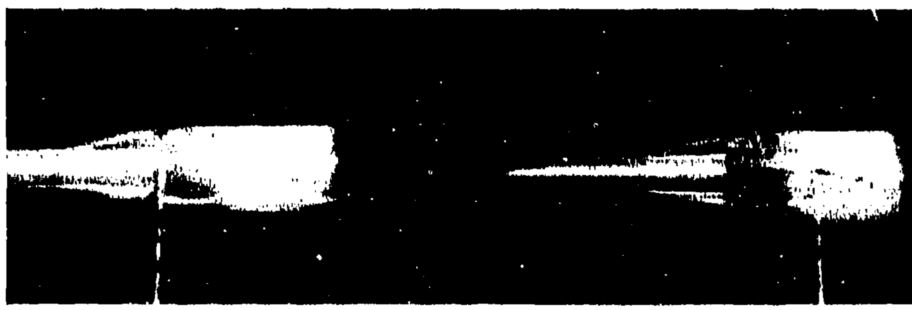


Figure 5 Double flash projectile photo.

2.3 TEST SERIES 2

For this series the apparatus was modified to substitute the use of flash X-ray photos for the optical photos of Series 1. Figure 6 illustrates the test configuration.

For these tests the weight of the pusher plate and the obturator were minimized by using a 1/8-inch-thick aluminum pusher and a 1-inch-thick polyethylene obturator. To avoid the obscuring effects of the impact of the pusher and obturator, these items were bolted to one of the four sabot sections. This modification did not prove to be successful. The opening of the sabot did not divert the heavier elements sufficiently far that they were removed by the sabot stripper. Furthermore, the asymmetry of the sabot opening process introduced an angular velocity to the projectile which resulted in an unpredictable angle-of-attack at impact.

The three shapes which were most successful in the first series (OC, FF and WF) were used in these tests together with two new shapes HF (similar to FF but with half height fins) and NF (body shape like FF but without fins). In this series the fins for FF and HF projectiles were welded to the body rather than pinned as in Series 1. For this series the weighted nose sections were threaded into the afterbodies, with only a single exception (HF-4), the projectiles remained intact throughout penetration.

2.4 TEST SERIES 3

A final test series was conducted with the goal of reducing the projectile velocity to approximately 1000 fps, eliminating the sabot pusher plate used in the previous test series, and improving projectile stability during launch and sabot stripping.

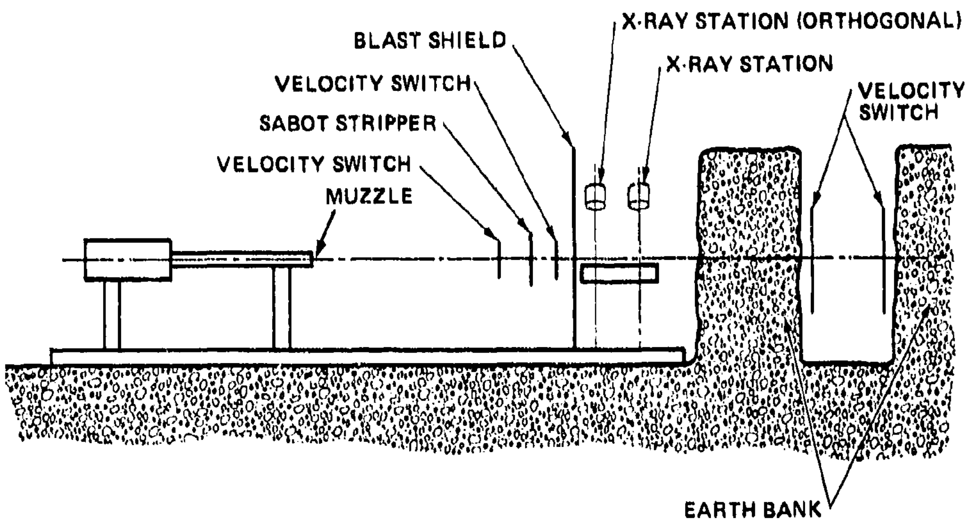


Figure 6 Experimental setup, Series 2.

Two projectile shapes, an ogive cylinder (OC) and an ogive nose with tapered body (OT), were fabricated from Bearcat steel. These projectiles were then impacted into soil and concrete-soil targets at a 20 degree oblique angle. The angle of attack was to be either 0 or 3 degrees.

A preliminary test series was conducted to determine the difficulties of reducing the projectile velocity. Simple solid projectiles with approximately the same L/D and areal density anticipated for the final tests were used for these velocity tests. Since the amount of powder required for these low velocities is so small, the 57 mm shell casings were cut down to 5 inches to allow placement of the SPM-2 powder directly around the ignitor in a paper tube container. This technique was felt to be desirable to cause rapid ignition of all the propellant grains. Several tests were then conducted in which varying powder weights were used. The projectile velocity versus C/M (charge weight to projectile weight ratio) is shown in Figure 7. The velocities from the final data tests are also included. The low scatter in velocity data was quite surprising in view of the fact that the sabot-projectile package did not contain a separate obturator to seal the propellant gases. The recorded projectile base pressures were less than 1800 psi, and the propellant grains were not completely burned during projectile launch.

The two projectile shapes used in this series with their respective sabots are shown in Figure 8. The projectiles were fabricated from AISI 5-7 (Bearcat) steel and heat treated to Rockwell C-55.

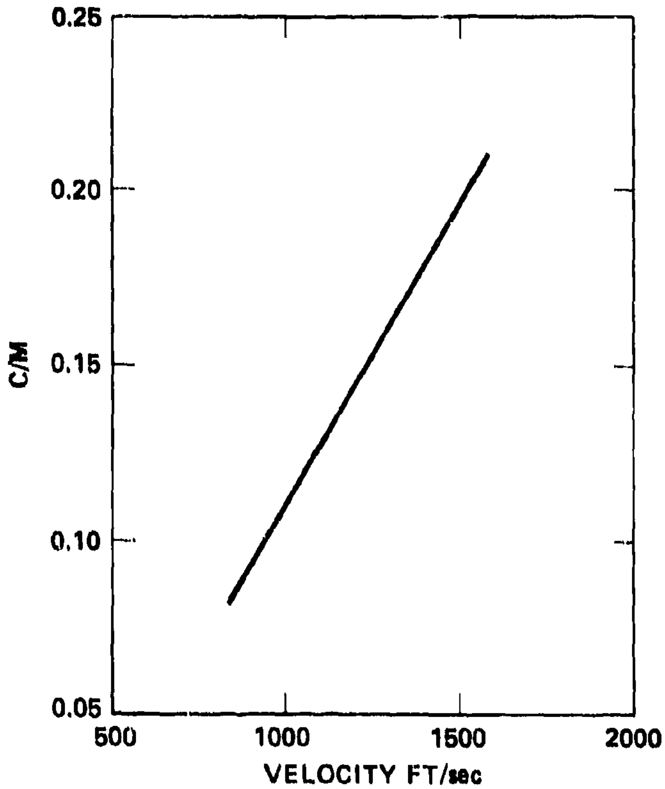
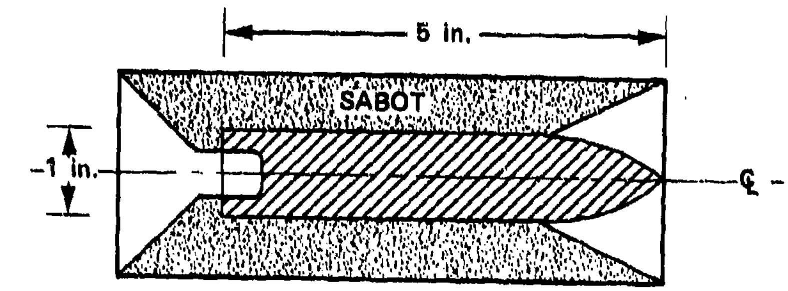
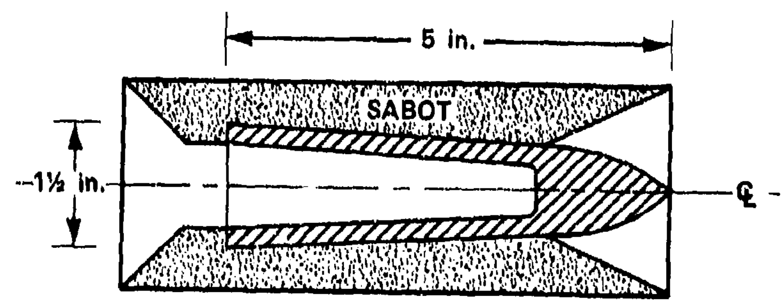


Figure 7 Projectile velocity versus c/m (charge mass/projectile mass).



O.C. PROJECTILE–SABOT PACKAGE



O.T. PROJECTILE–SABOT PACKAGE

Figure 8 Configuration of projectiles and sabots for EPW 3 tests (with ≈ 425 gms BEARCAT STEEL)

The sabots were made by casting epoxy in a four-piece mold. The epoxy used was "Epocast" No. 202 with No. 9652 hardener to which 7 percent by weight of microballoons was added to reduce shrinkage during curing.

Initial tests were conducted at approximately 1000 fps, however, at this subsonic velocity the sabot pieces did not separate sufficiently at the 2½-inch-diameter sabot stripper tube located approximately 9½ feet from the gun nozzle. Since relocation of the sabot stripper would cause additional cost and time delays, the velocity was increased to 1300 fps where successful sabot separation was achieved. The projectile still exhibited angular rotation caused by sabot separation but it was decided to continue with the testing and to carefully document the angle of attack upon impact.

The bank where the projectiles were impacted was cut to expose new, fresh soil. Although the soil in this area appears to be fairly variable between its clay and sand content, the "S" number determined by the DCP readings was fairly consistent. These readings in relation to the location of the projectiles is given in Figure 9.

The gun system was placed at an angle of approximately 20 degrees to the cut bank. The target area was then carefully trimmed to 20 degrees over approximately a 1-square-foot area for the soil-only tests.

For the concrete-soil tests, the concrete targets were placed approximately 2 inches from the bank and braced against the gun system. The void between the bank and concrete was then filled and tamped with moist native material. All angles were measured with an optical protractor viewed through the

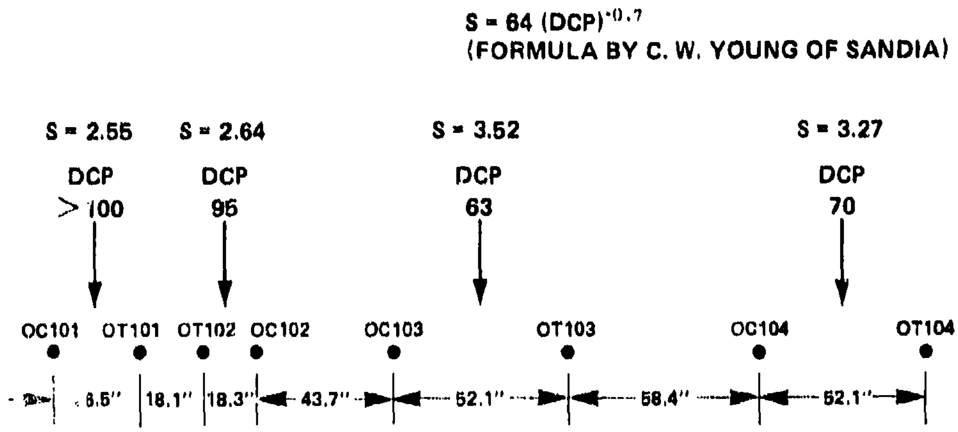


Figure 9 DCP (Dynamic Cone Penetrometer) readings relative to point of projectile impacts, Test Series 3.

barrel axis. Figure 10 is a photograph of this unit. The mix of concrete consisted of the following proportions:

Sand	254 pounds 63 percent
Type III Cement	94 pounds 23 percent
Water	55 pounds 14 percent (includes 5.7 percent sand moisture)

This mixture is different than that desired; it was necessary to add additional water and cement to achieve a workable mixture.

Compressive strength samples were taken of all pourings, however, some samples were usable due to separation planes caused by early movement of the samples. Compressive strength measurements of the samples tested were:

Target Pour Number	Number of Days After Pour	Compressive Strength (psi)
1	8	4389
3	9	4050
4	9	3230
7	9	4030
9	9	3530
10	9	4350
		Average 3928

The concrete was poured into forms that were 4 feet square and 2 inches thick. Six-inch square reinforcing mesh (0.225-inch-diameter wire) was centered in the form. The concrete was covered with plastic and kept moist for 5 days. Figure 11 shows the casting of the slabs.

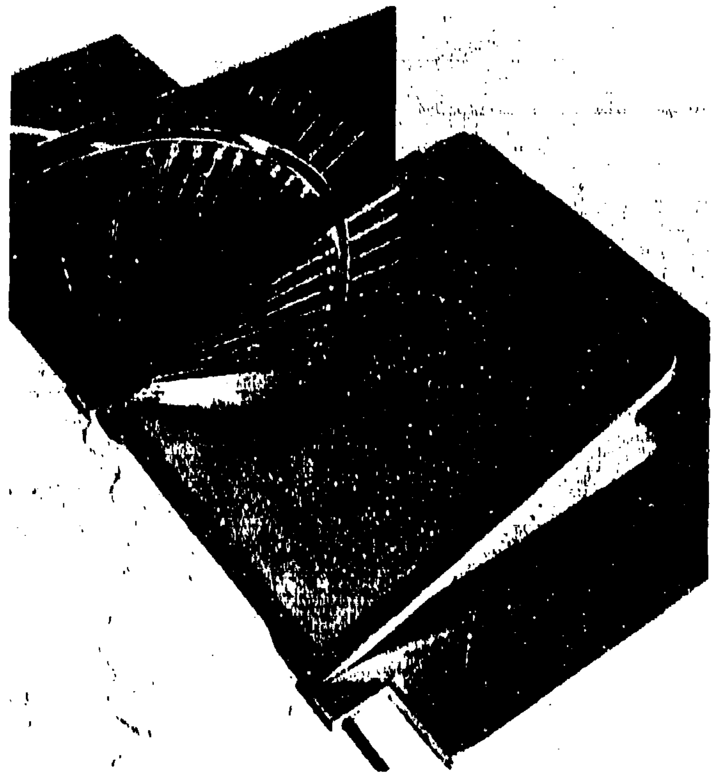


Figure 10   Optical protractor unit used for setting impact obliquity.

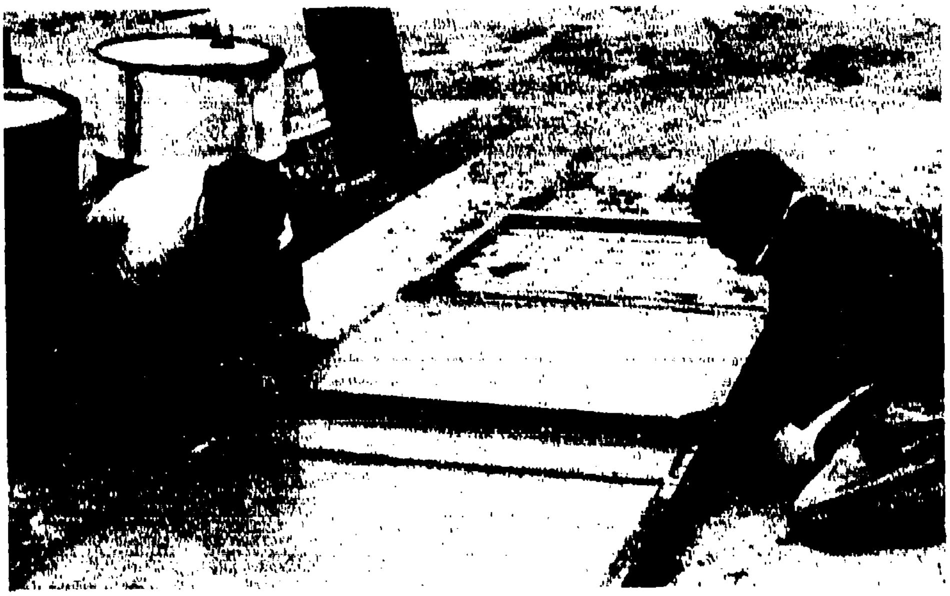


Figure 11 Casting of target slabs.

The diagnostics for the tests consisted of a muzzle break switch, two velocity screens on either side of the sabot stripper, and two X-ray locations located adjacent to the soil bank (see Figure 12). The final X-ray station consisted of an orthogonal X-ray pair for determining the projectile angle of attack and angle of rotation. The horizontal X-ray stations provided accurate projectile velocity information. The final orthogonal pair were positioned within 1 foot of the target to maximize data accuracy prior to impact. The X-ray data was analyzed with the aid of grid patterns that were pre-flashed on the film to provide accurate centerline locations and spatial scaling. Figure 13 is a typical X-ray photograph.

After all of these tests were completed, polyurethane expanding foam was forced into the holes produced by the projectile trajectories. After the foam was hardened, the soil was dug away and the foam castings were removed. A photograph of the recovered trajectories is shown in Figure 14.

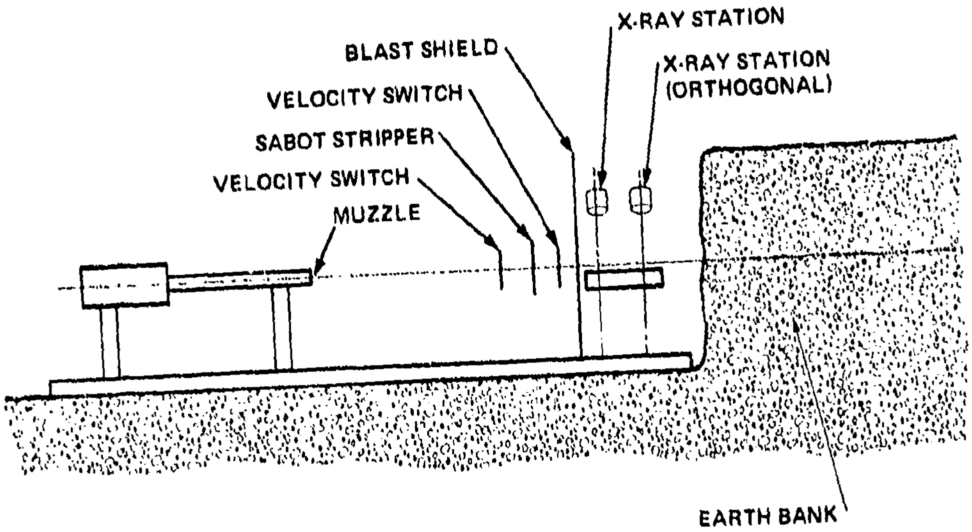


Figure 12 Experimental setup series 3.

Figure 13 X-ray photograph of projectile in flight.

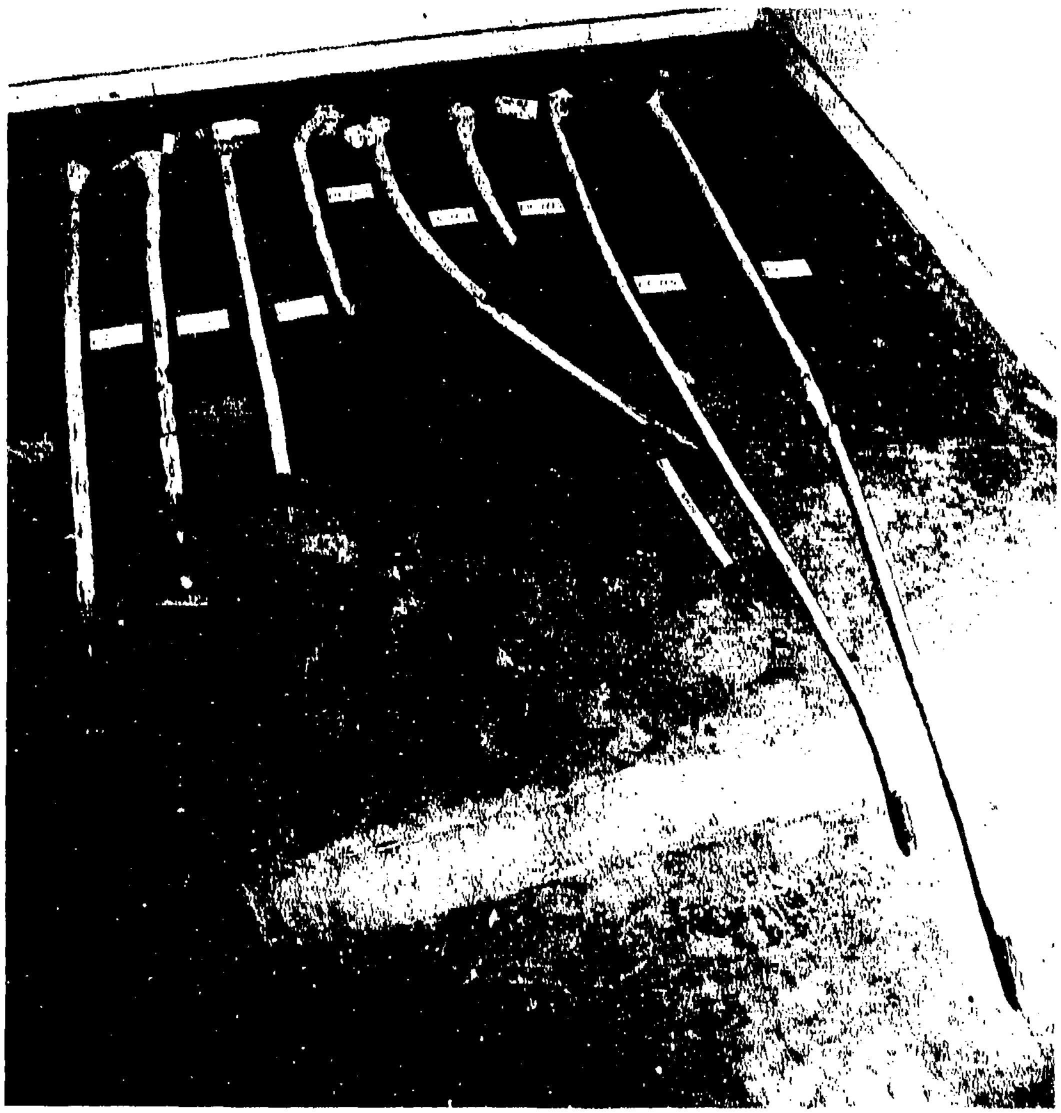


Figure 14 Recovered projectile trajectories from EPW series III.

SECTION 3

TEST RESULTS

Figure 15 defines angular measurements used in Table 1, 2, and 3, which present results. Figure 16 shows a summary of the trajectory obtained in Series 1 and 2. Figure 17 shows a comparison of total penetration depth and penetration efficiency for the seven shapes tested in Series 1 and 2. Penetration efficiency is defined as "useful" hole volume (projectile maximum cross sectional area times penetration depth) divided by kinetic energy at impact. Figure 18 shows similar properties for Series 3.

It should be noted that penetration between nominally identical experiments varies about ± 10 percent from a mean value. This value seems to be indicative of the magnitude of experimental variations which can be expected for these tests. These deviations are probably due to local variations of soil penetrability.

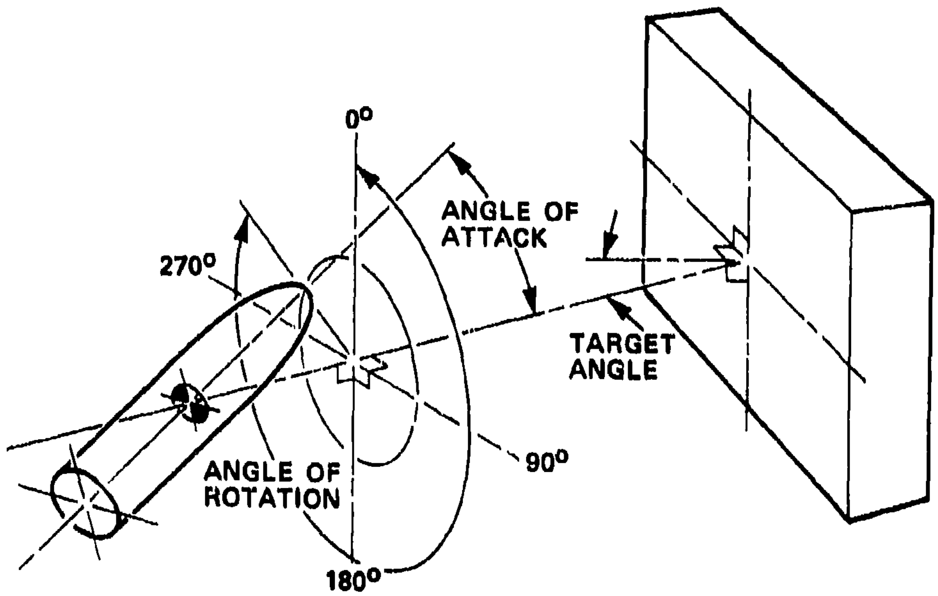
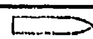
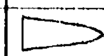
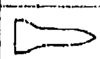
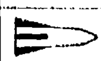
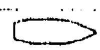


Figure 15 Projectile-target frame of reference and angle definition.

TABLE 1

DATA SUMMARY - EPW SERIES I

TEST NO.	PROJECTILE SHAPE	VELOCITY ft/sec	ANGLE(1) OF ATTACK degrees	PENETRATION 1st BANK	2nd BANK	NOTES
OC-1		820	0	68	–	
OC-2		2085	0	68	72	
OC-3		2046	3	20	–	DATA QUESTIONABLE
WF-1		1984	0	64	–	
WF-2		2065	0	68	16	
WF-3		1021	3	28	–	PUSHER STRUCK PROJECTILE PROJECTILE STRUCK STRIPPER
FT-1		2061	0	29	–	PROJECTILE TIP BROKEN
FT-2		2063	0	28	–	PROJECTILE TIP BROKEN
FT-3		2088	3	29	–	PROJECTILE STRUCK STRIPPER
FF-1		2116	0	49	12	TIP BROKEN – 2 FINS INTACT
FF-2		2063	0	61	36	3 FINS INTACT
FF-3		2047	3	–	–	PROJECTILE NOT LOCATED
BT-1		2100	0	62	–	36" PENETRATION BEFORE PROJECTILE TURNED 90°
BT-2		2105	0	48	–	32" PENETRATION BEFORE PROJECTILE TURNED 60°

NOTE (1): ANGLE OF ATTACK WAS NOT MEASURED PRIOR TO IMPACT

TABLE 2

DATA SUMMARY - EPW SERIES II

TEST NO. (2)	ANGLE OF ATTACK degrees	ANGLE OF ROTATION degrees	VELOCITY ft/sec	PENETRATION 1st BANK inches	2nd BANK inches	REMARKS
HF-2	2.3	17	2100	58	36	FINS LOST IN PENETRATION
HF-3	1.2	115	2008	62	40	FINS LOST IN PENETRATION
HF-4	4.1	331	2210	40	–	NOSE SEPARATED FROM BODY
HF-5	2.0	305	1915	48	23	FINS LOST
NF-1	3.7	208	1942	58	53	
NF-2	2.5	180	1802	?	?	
NF-3	3.0	16	1936	61	?	
NF-4	2.1	48	2042	59	45	
FF-4	1.3	345	2043	55	18	
WF-4	2.6	353	1833	53	–	
WF-5	6.1	111	1759	34	–	
OC-5	2.8	56	1930	66	84	
OC-6	3.5	82	1992	59	78	

NOTES: (1) TARGET BANK NORMAL TO GUN AXIS
(2) HF INDICATES HALF SIZE FINS. NF INDICATES CONICAL BODY WITHOUT FINS
WF INDICATES WIDE ANGLE CONE. OC INDICATES OJIVE NOSE AND A CYLINDRICAL BODY

TABLE 3

DATA SUMMARY - EPW SERIES III

	PROJECTILE				TARGET				
TEST NO.	VELOCITY ft/sec	ANGLE OF ATTACK degrees	ANGLE OF ROTATION degrees	MASS gms	TYPE	SOIL[2] "S" NO.	CONCRETE[1] COMPRESSIVE STRENGTH	ANGLE degrees	PENETRATION PATH LENGTH inches
OC101	1286	3.0	24	425.3	SOIL	2.4		19	110½
OC102	1304	4.4	264	428.6	SOIL	2.7		19	92¼
OC103	1284	7.9	318	425.2	CONCRETE-SOIL	3.4	4050 psi	20	80
OC104	1309	7.7	227	426.0	CONCRETE-SOIL	3.3	4030 psi	19½	68
OC101	1286	3.0	137	427.0	SOIL	2.5		19	71
OC102	1269	4.3	185	424.5	SOIL	2.6		19	57½
OT103	1299	9.8	313	427.1	CONCRETE-SOIL	3.4	-- --[3]	20	58¾
OT104	1286	4.9	150	425.1	CONCRETE-SOIL	3.4	3230 psi	19½	67½

NOTES: (1) CONCRETE THICKNESS = 2.0 inches. AVERAGE COMPRESSIVE STRENGTH OF 7 SAMPLES = 3928 psi (9 DAY – SAME DATE AS TESTS)

(2) ESTIMATED "S" NUMBER FROM 4 DCP READINGS AND THE FORMULA $S = 64\ (DCP)^{-0.7}$

(3) THE SAMPLE FOR THIS POUR WAS UNUSABLE. THE MIX WAS IDENTICAL AND CONDITIONS WERE SIMILAR SO WE SUGGEST THE 3928 psi AVERAGE VALUE BE USED.

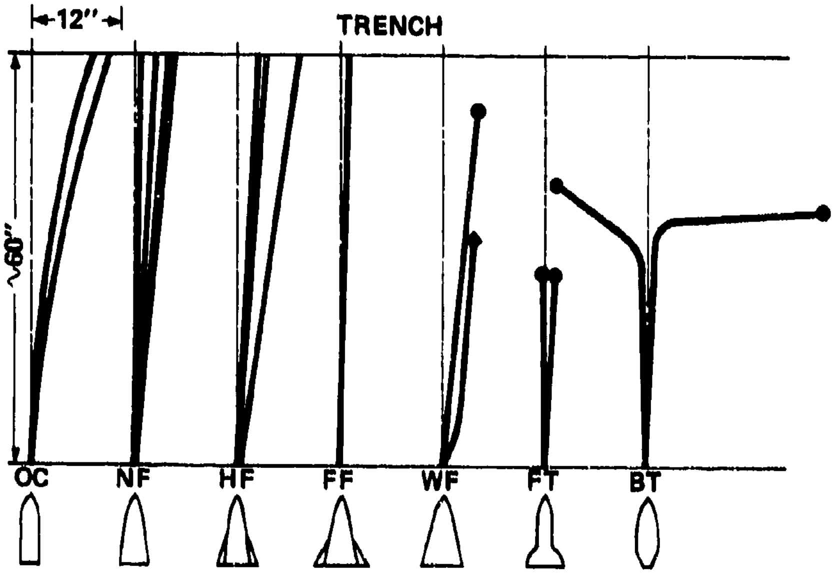


Figure 16 Trajectory stability, Series 1 and 2. (Deviations are schematic and approximate.)

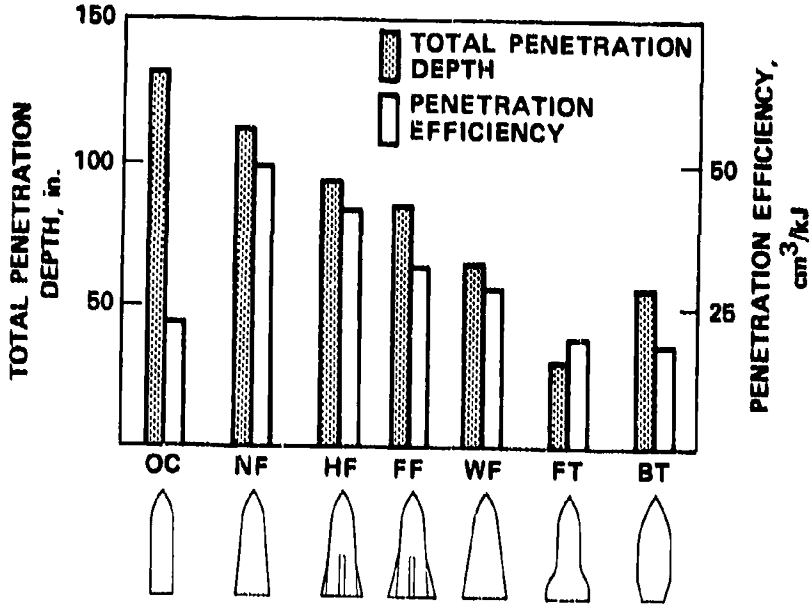


Figure 17 Total penetration depth and penetration efficiency for seven projectile shapes, Series 1 and 2.

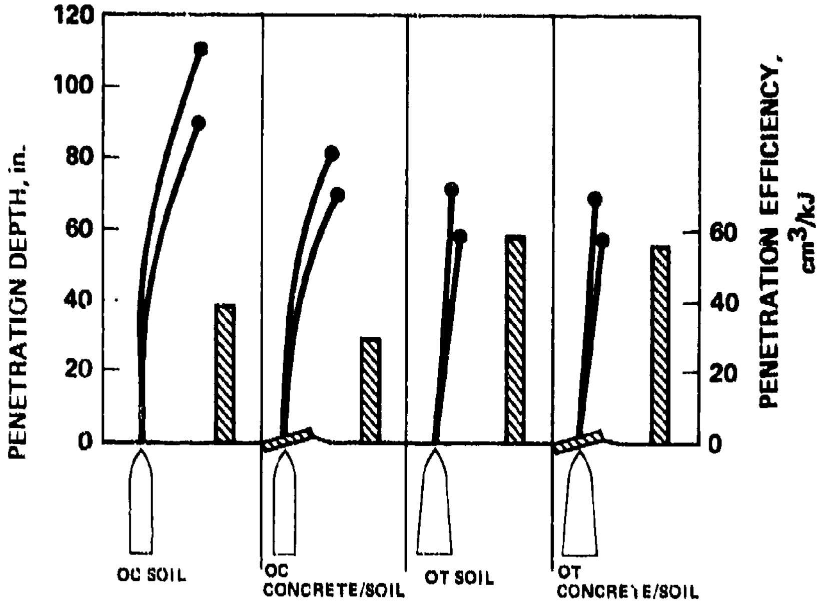


Figure 18 Penetration trajectories and efficiencies.

SECTION 4

SUMMARY AND CONCLUSIONS

The following list summarizes the results of the experiments conducted during this program.

1. Of the seven projectile shapes tested only one, the boat-tailed projectile, did not exhibit a stable trajectory.

2. Projectiles with ogive noses and cylindrical bodies (OC) veered slightly while penetrating.

3. The trajectories of all other projectiles were very straight even at angles of attack as high as 10 degrees and obliquities of 20 degrees into a concrete clad target.

4. The ogive cylinder projectiles showed the deepest penetration.

5. The ogive nose projectiles with a narrow conical afterbody showed the greatest penetration efficiency (hole volume produced for a given kinetic energy at impact).

6. The additional stabilization provided by fins does not seem to be required for penetrators of these L/D ratios.

7. Two inches (0.4 body length) of concrete reduced penetration by about 35 percent for cylindrical (OC) projectiles and almost none for conical body (OT) projectiles.

8. Erosional patterns seem to show continuously attached flow for the conical body shapes (NF, HF, FF, WF and OT).

9. We were unable to launch projectiles with predictable angles-of-attack except by using obturators which obscured the first few body lengths of penetration data.

10. A self obturating sabot was developed which satisfactorily launched projectiles without any following material to obscure penetration data.

APPENDIX A

PHOTOGRAPHS OF TEST APPARATUS AND RESULTS

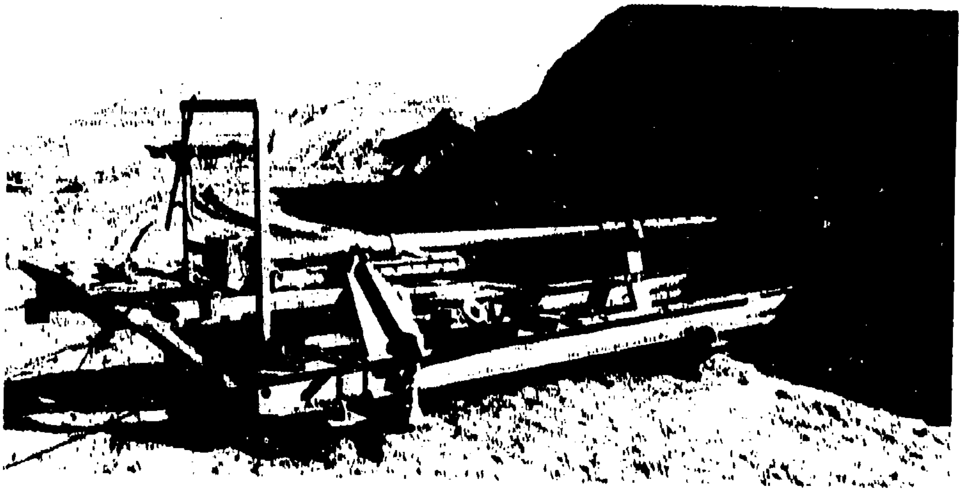


Figure A-1   Projectile launching apparatus in place.

Figure A-2 Impact point and X-ray tubes and film holders.

Figure A-3 Truncated shell casing and powder charge.

Figure A-4   Barrel alignment sighting tool.

Figure A-5 OC projectile and sabot.

Figure A-6 Velocity switch showing projectile and sabot impacts.

Figure A-7 Impact point--concrete clad target and X-ray film holder.

Figure A-8 Penetrated concrete target.

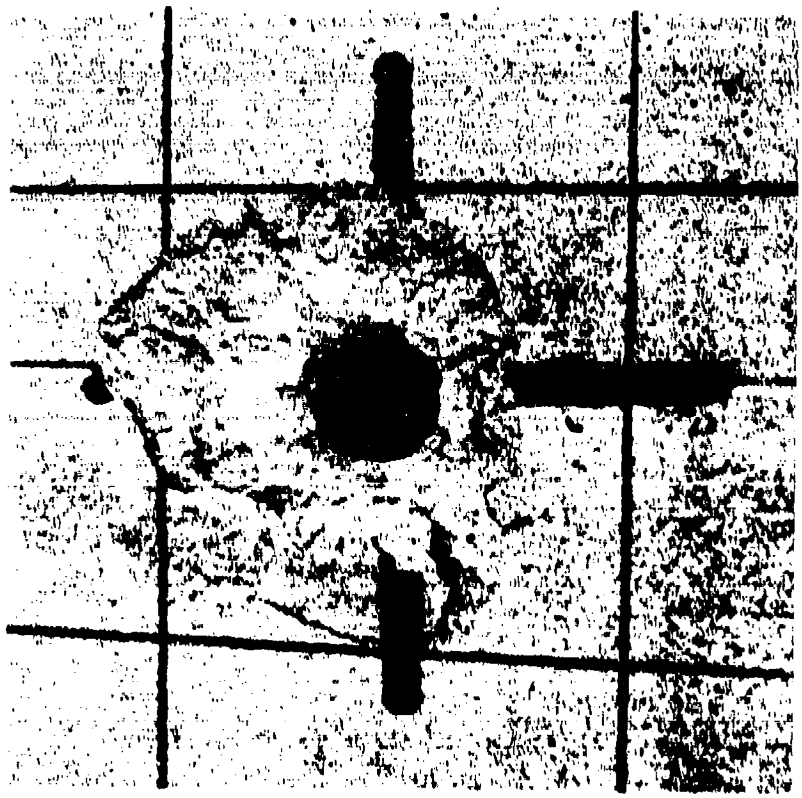


Figure A-9 Penetrated concrete target.

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